Diamond Bay

Sonoma Technology Inc.

ANALYSIS OF AEROMETRIC AND METEOROLOGICAL DATA FOR THE VENTURA COUNTY REGION

FINAL REPORT

STI #90094-511-FR

Contract #83-8.0.05(3)-14-01-SOT

Prepared for:

WESTERN OIL & GAS ASSOCIATION (WOGA)
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Los Angeles, CA 90017

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ABSTRACT

The objectives of the analyses presented in this report are to determine the physical transport mechanisms by which ozone or its precursors are transported from Los Angeles to Ventura County, and to estimate the frequency of occurrence and the contribution to Ventura County ozone concentrations of such transport.

Analyses of data obtained during the Ventura County Ozone Transport (VCOT) Study in September 1983 are presented along with analyses of air quality and meteorological data from 1980-1983. Trajectory model results from selected trajectories from the VCOT Study are also presented. During the VCOT Study, surface and airborne meteorological and air quality measurements were made throughout Ventura County.

Transport from Los Angeles to Ventura County appeared to occur along both coastal and inland routes at the surface and aloft. On days of low mixing heights (<250 m msl), the surface transport routes were favored, and the coastal valley sites could be impacted. Higher mixing heights resulted in elevated layers which could impact the higher elevation coastal and inland sites.

The upper winds at about 1,000 m msl at Point Mugu were used as an indicator of potential transport from Los Angeles to Ventura County. On the average for summer months, ozone concentrations at most Ventura County sites were about 10% higher on days of potential transport than on "non-transport" days. "Transport" winds occurred on about 59% of summer days. During September, "transport" winds were more frequent than in other months, and average ozone concentrations were 40-50% higher on "transport" than on "non-transport" September days at most Ventura County sites.

A photochemical trajectory model was used to simulate five cases where Ventura County ozone exceeded 12 pphm and transport of ozone into the county was likely occurring. The model results indicated that a large fraction of the ozone predicted in Ventura County for these days was due to ozone and its precursors transported from Los Angeles County. Although the model and available input data are too uncertain to precisely quantify the transport component, the model results qualitatively indicate that it can be large under certain meterological conditions.

The data analyses and model results from the VCOT study both indicate that ozone and ozone precursors transported from Los Angeles County can lead to significantly increased ozone concentrations in Ventura County when meteorological conditions are conducive to such transport.

ACKNOWLEDGEMENTS

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The report would not have been possible without the efforts of several groups who collected, processed, and provided us with much data which was not already available to us through the Ventura County Ozone Transport Study. Specifically, we gratefully acknowledge the contributions of the following groups.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION, OBJECTIVES, AND PROJECT DESCRIPTION

1.1 INTRODUCTION

Potential oil development on the outer continental shelf offshore of the south central coast of California has raised concerns among regulatory agencies about the impact this development will have on air quality in the adjacent counties. In response to these concerns, the Western Oil and Gas Association (WOGA) has funded several studies of air quality in the region. In 1983, Environmental Research and Technology (ERT) reviewed prior studies for WOGA in order to summarize what was then known about the causes of air quality degradation in the region (Godden and Lague, 1983). This review and additional analyses by Smith et al. (1983) of data from the Santa Barbara Oxidant Study (Lehrman et al. 1981) suggested that transport from the neighboring Los Angeles Basin was probably a significant contributor to high ozone concentrations in Ventura County. It was also apparent that these transport* processes were quite complex, involving day-to-day carryover and elevated layers. The details of the transport mechanisms and the frequency and amount of the transport contribution, however, were not understood.

To address these issues and to provide insights for model development, WOGA sponsored the Ventura County Ozone Transport (VCOT) study in September 1983 and subsequently sponsored the analysis of the VCOT data. This report presents the results of the VCOT study analyses as well as some additional analysis of data from prior years.

The VCOT study was conducted from September 1, 1983 through October 6, 1983, by Sonoma Technology Inc. (STI). Portions of the study were performed under subcontract to STI by AeroVironment, Inc. (AV), Environmental Research and Technology, and Meteorology Research, Inc. (MRI). An instrumented aircraft and supplementary ground based monitors were used to measure the transport of ozone and ozone precursors into Ventura County from Los Angeles (L.A.) County and the three-dimensional distribution of ozone and ozone precursors within Ventura County. The VCOT measurements and the data obtained are presented in a report by Lehrman et al. (1983).

This report was prepared by STI and ERT. Three types of analyses are reported:

1. Case studies of the VCOT study data were performed to determine the transport mechanisms by which ozone or precursors from the L.A. Basin contributed to Ventura County ozone concentrations.

2. Statistical analyses were performed for the VCOT data to assess those meteorological conditions leading to high ozone and to ozone transport in Ventura County. Indicators were developed by which the frequency of transport could be assessed over a longer period than that of the study. Four years of data were then used to determine the frequency of occurrence of days on which transport was likely to be an important contributor to Ventura County ozone concentrations and to assess the representativeness of the September 1983 study period.

3. Determination of the contribution of transported ozone or precursors to surface concentrations is complicated by enroute

* In this report, the term "transport" is generally intended to mean transport from Los Angeles County to Ventura County.

chemistry and local emissions. To provide a rough estimate of the incremental contribution of transported pollutants, a trajectory model was run for selected days and receptors.

The VCOT study was a small exploratory study. The analyses presented here are limited by the constraints of the VCOT data set. This report presents new insights that we have obtained from the data, but it is not a comprehensive analysis of this complex problem and is not intended to answer all questions about the contribution of transport to Ventura County ozone concentrations.

The remainder of this section outlines the objectives of the analyses performed and briefly describes the VCOT measurement program. Section 2 summarizes the conclusions and recommendations from the analyses, and Section 3 presents a conceptual model with case study examples of the synoptic conditions and flow patterns leading to transport.

The details of the analyses are presented in subsequent sections. Section 4 presents several statistical descriptions of the study period. Section 5 assesses the relationships of high ozone in Ventura County to transport and meteorological conditions. The frequency of occurrence of ozone transport into Ventura County is discussed in this section. Section 6 discusses the representativeness of the September 1983 study period, and Section 7 presents the results of trajectory model runs for several transport situations.

1.2 OBJECTIVES

The objectives of this project were to:

1) determine the physical transport mechanisms by which ozone or ozone precursors were transported into Ventura County during the VCOT study period;

2) develop synoptic indicators which correspond with intercounty transport and which can be used to predict such transport and assess its frequency of occurrence;

3) use historical synoptic data and statistical indicators of transport to estimate the representativeness of the VCOT data set and to estimate the frequency and amount of transport of ozone and its precursors;

4) through trajectory model simulations, estimate the sensitivity of surface ozone levels to the ozone and precursor input due to transport; and

5) identify gaps in knowledge and their implications for model development.

1.3 OUTLINE OF VCOT MEASUREMENT PROGRAM

During the study, the STI aircraft made 56 flights, typically three times per day, over a standard route. Airborne measurements included ozone (O_3), nitrogen oxide (NO), total oxides of nitrogen (NO_x), light scattering coefficient, temperature, altitude, and position. Ozone was measured by STI at the Navy facility at Laguna Peak at about 450 m msl elevation. Time-lapse photographs were taken by STI throughout the project during daylight hours at Laguna Peak (2 cameras) and at Big Mountain above Simi Valley. Upper air winds were measured in the Simi Valley with a Doppler acoustic sounder which was operated by AV. Upper winds were also measured at the Ventura Marina using pilot balloons during selected periods of the study by MRI. The data base was augmented by obtaining data from sources external to the project. Ozone and other pollutant monitoring data were obtained from the Ventura County APCD (VCAPCD), the California Air Resources Board (CARB), and Rockwell International (RI) at Rocketdyne. Supplementary meteorological data were obtained from the VCAPCD, the Navy at Point Mugu and Laguna Peak, the FAA at Santa Barbara and Ventura Airports, and RI at Rocketdyne.

Figure 1-1 is a map of the surface monitoring locations discussed in this report, and Figure 1-2 is an outline of the standard flight pattern. The flight pattern consisted of a series of vertical spirals which were generally made from near the surface to the top of the haze layer (1000 - 1500 m msl). Typically, flights were made each day at dawn, midday, and mid-afternoon following the standard pattern. The flights were designed to provide routine observations of the vertical and horizontal distribution of pollutants along the perimeter between Ventura County and the South Coast Air Basin, and to define the vertical temperature and pollutant structure in the boundary layer at several locations. On selected days, the sampling area was extended to include northern portions of Ventura County.

A summary of the meteorology, air quality, and sampling flights during the sampling period is presented in Figure 1-3. The morning 850 mb temperature is plotted as a general indicator of stability and regional stagnation. The peak hourly ozone values measured each day by the VCAPCD are plotted as an indicator of air quality. The occurrence of sampling flights is indicated at the bottom of the figure. Standard or extended sampling flights are indicated by an "S" or "X". Flights cancelled because of weather are indicated by a "W". In general, weather cancellations were due to excessive low clouds or occasionally to rain. The meteorology of the period was unusual for September in that the period was cloudier than usual, and storms were encountered late in the sampling period. The sampling period was also a period of uncommonly persistent southeasterly flow aloft, providing numerous opportunities for intercounty transport. There were 16 days during the sampling period when the federal ozone standard of 0.12 pphm was exceeded in Ventura County.

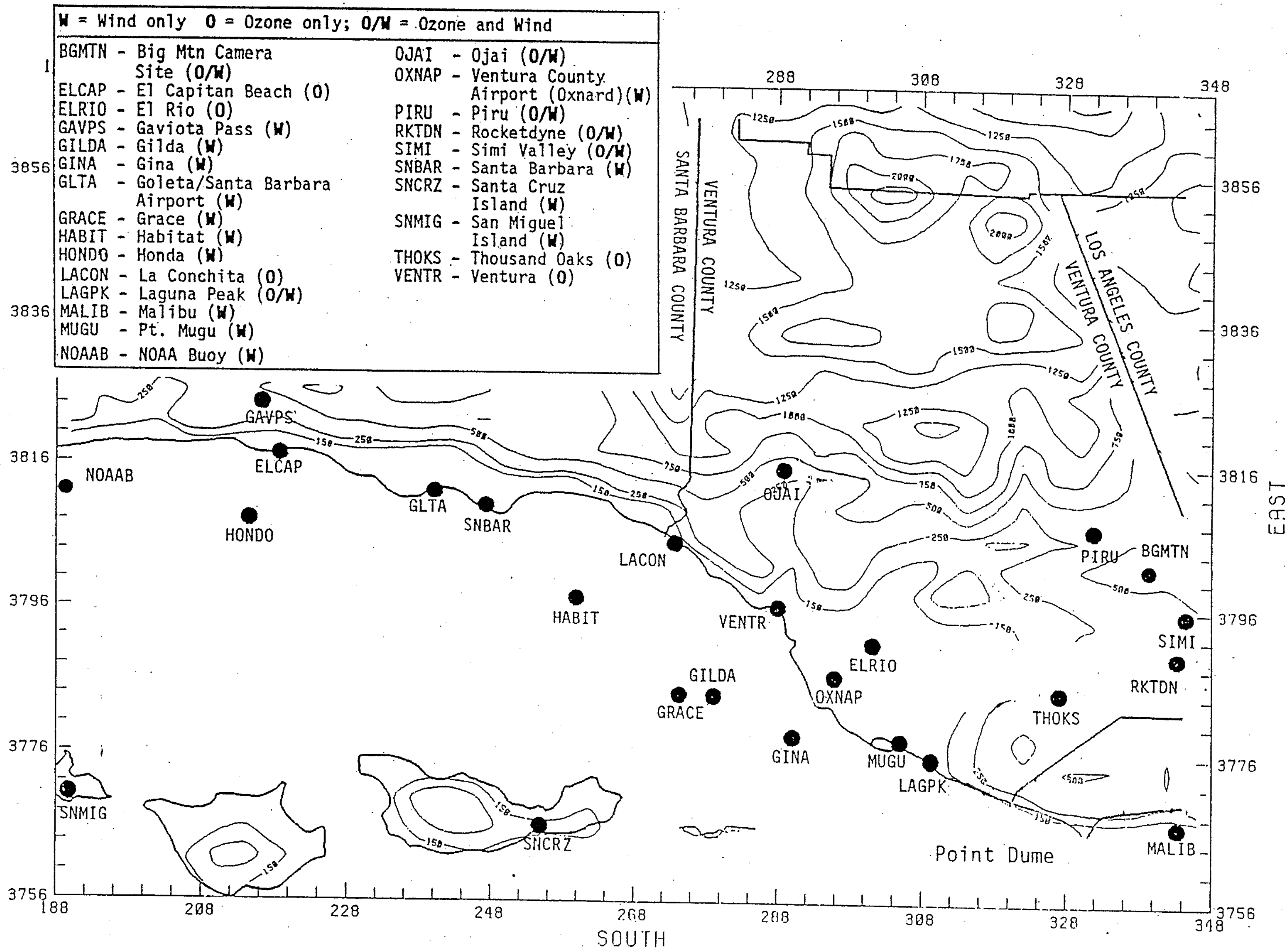

Figure 1-1. Locations of the VCOT Study Surface Monitoring Sites

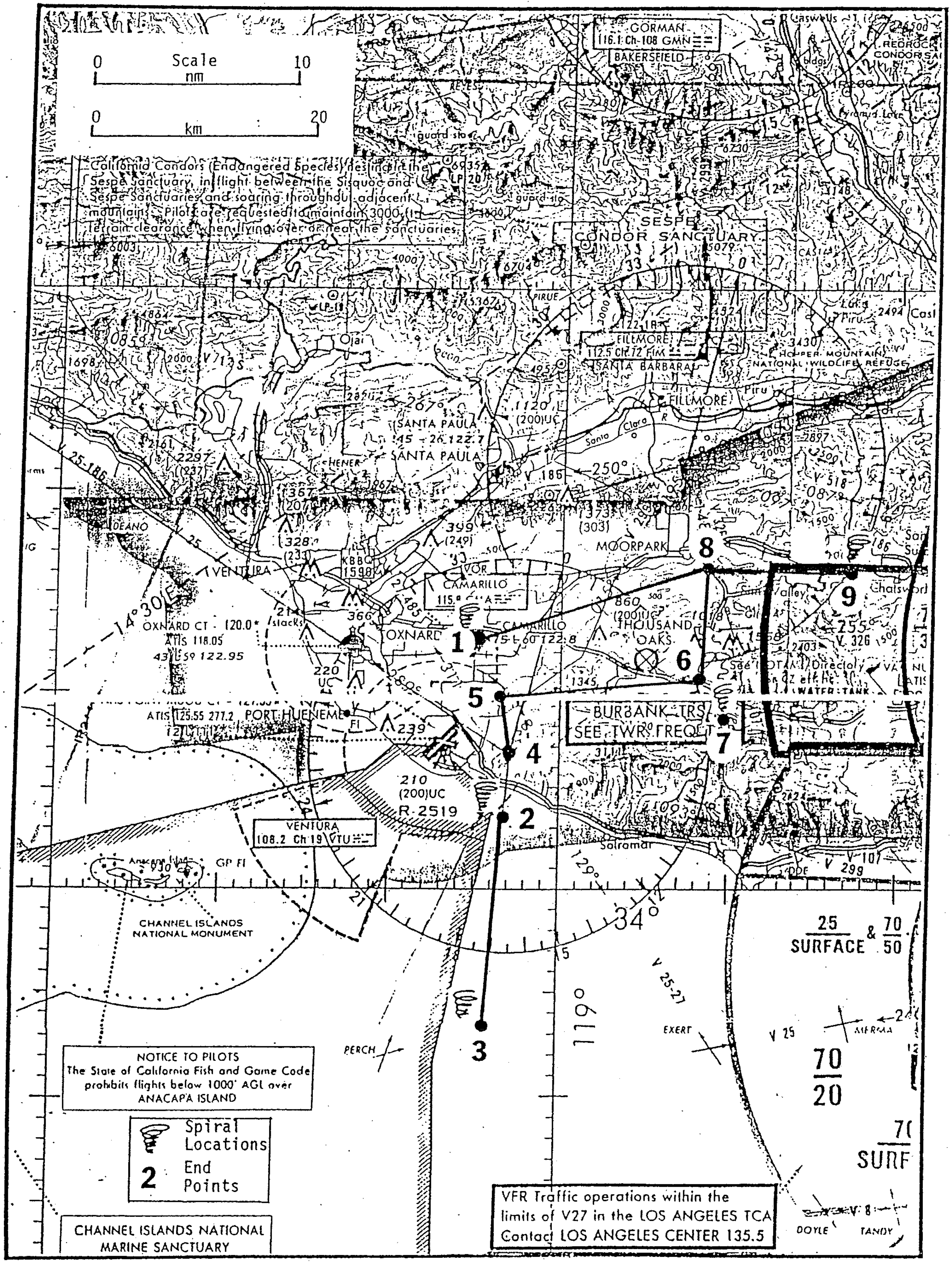

Figure 1-2. Standard Flight Pattern

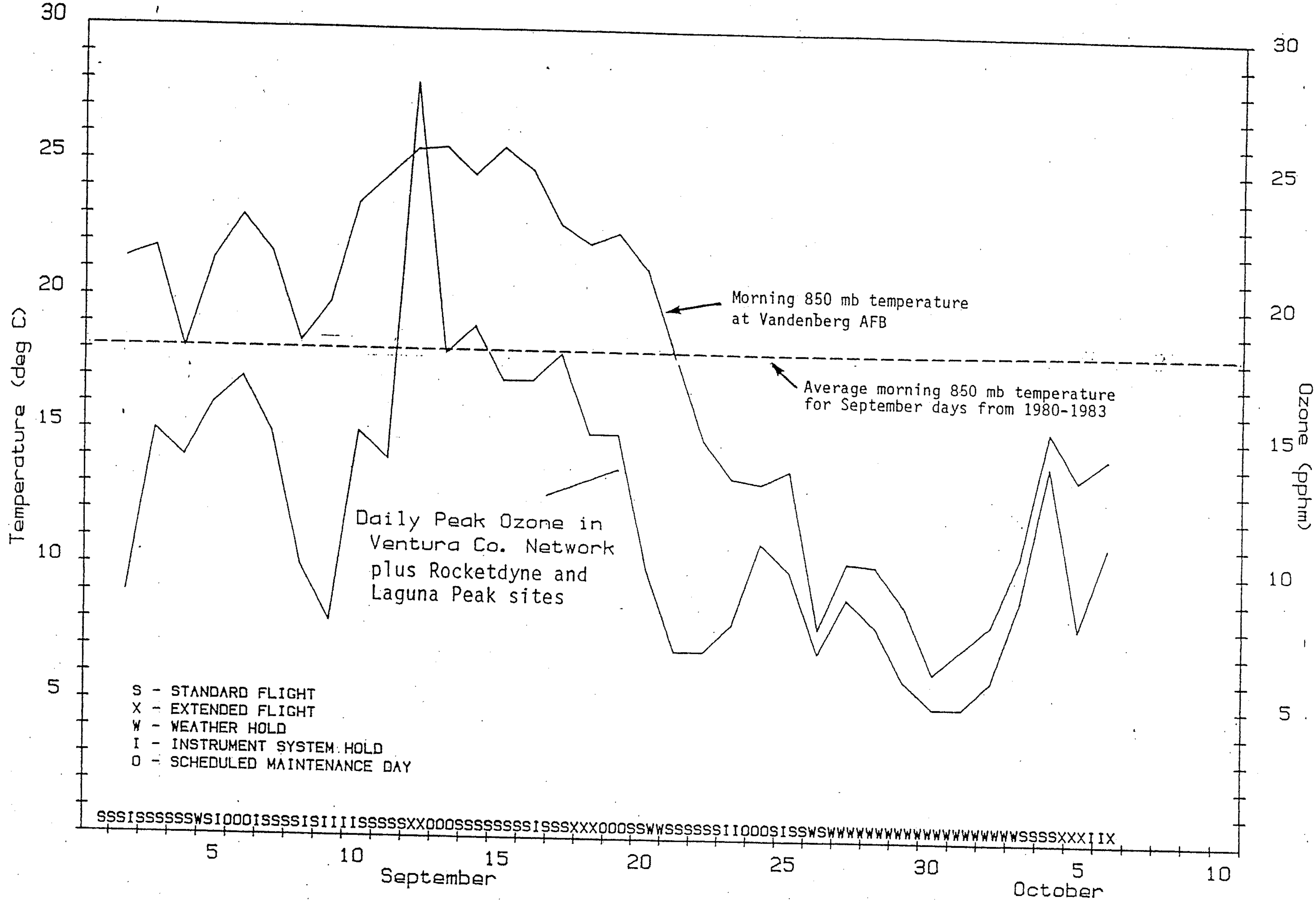

Figure 1-3. Sampling Flight Summary with Air Quality and Meteorology Indices

2. CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

The conclusions drawn from our analyses of the VCOT Study data and the available 1980-1983 air quality and meteorology data are summarized below.

1. This study and others have shown that pollutants transported from the Los Angeles Basin can be important contributors to coastal and inland ozone concentrations in Ventura County. The upper air wind data at Pt. Mugu indicate that over half the days in each summer month have the potential for such transport contributions. The average percentage of occurrence of potential transport days for June-October, 1980-1983 was 59%. September is clearly the month with the most substantial potential transport effects. June and October have the lowest frequencies of occurrence of potential transport. From this study, however, it does not appear that transport is a prerequisite for exceedances of the Federal ozone standard (12 pphm) to occur in Ventura County.

2. Analysis of the VCOT Study data suggested four mechanisms by which transport can lead to increased Ventura County surface ozone concentrations. Transport was apparent across the Simi Hills (inland route) and along the coast (coastal route). Transport along both routes occurred at the surface and aloft.

   Pollutants transported at low levels (< 250 m msl) along the coast appear to impact coastal valley sites such as El Rio and Ventura. Pollutants transported along the coastal route at higher elevations can directly impact the elevated sites in Ventura County such as Laguna Peak. In addition, elevated coastal pollutants can be brought to the surface farther inland by thermal mixing and can impact areas such as Ojai and Piru. All exceedances at the coastal sites of El Rio and Ventura in June-October from 1980-1983 occurred on days when the air flow aloft was northeasterly through southerly.

   Pollutants transported along the surface from the San Fernando Valley can directly impact areas in eastern Ventura County such as Simi and Rocketdyne. Pollutants transported aloft along the inland route can be brought to the surface by thermal mixing at inland sites near the hills such as Simi, Piru, and Thousand Oaks.

3. The September 1983 VCOT Study period was chosen to look for transport. This period, in fact, had a higher frequency of potential transport days than usually occurs in the summer. During the study, the Ventura County region was affected more than usual by clouds and by tropical moisture, but the 850 mb temperatures and the average ozone maxima were quite close to the averages for Septembers from 1980-1983. Although the VCOT Study period might not be representative

of other summer months, the transport mechanisms suggested by the VCOT data include virtually all feasible transport routes from Los Angeles to Ventura County. Thus, it is likely that the transport mechanisms suggested by the 1983 study are typical of those that occur in other months or years. The frequency of occurrence of the mechanisms, however, is likely to be different during the other summer months. During the 1983 study, all exceedances of the 12 pphm federal ozone standard in Ventura County occurred on days when the wind fields suggested potential transport.

4. The impact of transport into Ventura County depends to a great extent on the depth of the associated mixing layer. Shallow mixing depths tend to produce high ozone concentrations along the immediate coast while deeper mixing layers result in a more elevated ozone layer and impact on the higher elevation inland areas.

5. High (> 12 pphm) ozone days during the VCOT Study typically had the following characteristics:

   - 850 mb temperature was > 20^{o}C
   - Elevated ozone layers existed, especially offshore near Laguna Peak
   - Flow aloft had an easterly component
   - Ozone concentrations were high throughout the South Coast region for extended periods
   - The air mass was relatively stagnant, with mixing heights < 3000'
   - Boundary layer background ozone at approximately 3000' was relatively high: 5-9 pphm.

6. From the 1980-1983 data set, a good indicator of high ozone concentrations in Ventura County was the 850 mb temperature. The 850 mb temperature was greater than 20^{o}C on 66% of exceedance days in Ventura County but on only 17% of non-exceedance days.

7. Maximum ozone levels measured in Ventura County for the 1980-1983 data base were well correlated with levels measured in the South Coast Air Basin. This implies that ozone episodes in Ventura County are typically a regional phenomenon.

8. From the VCOT Study analyses, the 3000' wind direction from the midmorning Pt. Mugu sounding was chosen as an indicator of the potential for transport, with directions from 45^{o} to 180^{o} indicating the potential for transport from Los Angeles County. Days meeting this criterion were considered potential "transport" days for the purposes of various statistical analyses.

For Conclusions 9 - 13 below, the indicator above is used to classify potential "transport" days for the June-October, 1980-1983 Ventura County data.

9. "Transport" and "non-transport" days have similar 850 mb temperature distributions. However, the average 850 mb temperature on "non-transport" exceedance days in Ventura County is higher than for "transport" exceedance days. Thus more trapping and stability is required to exceed the standard on a "non-transport" day.

10. For the summer season at all sites but Ojai, a higher percentage of "transport" days than "non-transport" days had exceedances. In addition, "transport" days accounted for 59% of all days in the four year data set, so most exceedances at most Ventura County sites occurred on "transport" days. The Ojai site appears to be an exception and on the average had lower ozone on "transport" than "non-transport" days. Thus, on the average, Ojai appears to be less affected by transport from L.A. County than other sites in Ventura County.

11. The transport contribution to Ventura County ozone concentrations is most important during September. Exceedances in September at the coastal valley and Thousand Oaks sites only occurred on "transport" days. About 70% of September days in the four year data set were "transport" days. For September, about 46% of "transport" days were exceedance days compared with only 19% of "non-transport" days.

12. On the average for the summer months, the percentage of "transport" days which were exceedance days (O_3 > 12 pphm) in Ventura County was slightly higher than the percentage of "non-transport" (48% vs. 42%). However, the percentages of "transport" vs. "non-transport" days which saw ozone greater than 15 pphm were more biased in favor of "transport" days (21% vs. 14%).

13. For the summer as a whole, the median maximum ozone concentrations at most Ventura County sites were about 10% higher for "transport" than for "non-transport" days. The median maximum ozone concentrations at Ojai and at the San Fernando Valley (L.A. County) sites were higher on "non-transport" days. In September, however, the median maximum ozone values for all sites were higher on "transport" than "non-transport" days, and the Ventura County median maxima were 40-50% higher at many sites on "transport" days.

14. A photochemical trajectory model was used to simulate five cases where Ventura County ozone exceeded 12 pphm and transport of ozone into the county was likely occurring. For these simulations, the ratios of observed to predicted ozone concentrations at the receptor sites averaged within 10% of one for ozone maxima from 140-230 ppb. The model results indicated that a large fraction of the ozone predicted in Ventura County for these days was due to ozone and its

precursors transported from Los Angeles County. Although the model and available input data are too uncertain to precisely quantify the transport component, the model results qualitatively indicate that it can be large under certain meterological conditions.

Sensitivity tests showed that the model predictions were much more sensitive to the initial upwind ozone concentrations than to the initial hydrocarbon or NO_x concentrations.

15. The model results and the VCOT Study results indicate that, on some days, transport can be the dominant factor influencing Ventura County ozone concentrations. These transport contributions are especially important in September and were often dominant during the September 1983 VCOT Study. For the summer as a whole, however, the very high transport components for specific days are diluted in the statistics; the average increase on "transport" days over "non-transport" days is probably more like 10% at most sites in Ventura County. It does not appear that transport is a prerequisite for exceedance of the federal ozone standard.

2.2 GAPS IN KNOWLEDGE AND IMPLICATIONS FOR MODEL DEVELOPMENT

This study has provided a great deal of insight into the transport processes contributing to ozone concentrations in Ventura County. The quantification of the relative contributions of various local and regional sources to ozone concentrations in Ventura County, however, is still subject to a large uncertainty on any given day. To quantify these contributions for specific days or to develop and assess control strategies, it is likely that a sophisticated modeling effort will be needed. Such an effort will need a greatly expanded data base for development and evaluation purposes.

This study has also shown that elevated layers occur frequently in the Ventura County region and impact elevated terrain. The concentrations at the elevated locations can far exceed those measured at valley floor locations. No long term data exist on the magnitude or frequency of this impact or on the effects on vegetation or people at the higher elevations near the coast.

From the 1980-1983 data, it is clear that the transport processes vary from month to month and that any modeling performed should be done for a variety of wind field and meteorological situations. Thus, the data collection effort needed to support the modeling should provide data representative of the spectrum of meteorological regimes seen throughout the summer.

Some specific information needs are outlined below.

1. In order to properly model the transport processes, much more information on the wind fields aloft and offshore will be needed. Diurnal data onshore aloft will be needed to properly predict the

transport of elevated layers. The wind field in the channel at night is quite complex and varies from one night to the next. The nocturnal wind field strongly influences the offshore transport of pollutants. Additional three-dimensional, diurnal wind field data will be needed to assess the offshore circulation patterns and to distinguish pollutants which have been transported into Ventura County from those which have just gone offshore during the night and returned the next day.

2. Mixing downward of ozone from aloft has been indicated along the immediate slopes of the Simi Hills where the mixing layer rises rapidly in mid-day. To the west of this region, the vertical structure over the coastal area is more stratified, and ozone transported from the east tends to remain in distinct layers. The fate of these layers is not certain. They can impact elevated terrain and, if very low, can sometimes affect surface concentrations. However, if they are not carried to the surface, their fate on subsequent days is unknown.

3. The boundary layer background air quality in Ventura County can vary considerably depending on the trajectory of the air arriving in the area. To model surface ozone concentrations, it will be necessary to have good measurements of the background ozone aloft over the region for the types of days to be modeled.

4. There is evidence that ozone and precursors in layers aloft carried over from the previous day, but separated from destructive influences near the surface, may continue reacting when irradiated on the second day. These elevated layers may influence surface concentrations when mixed to the ground in inland areas. The chemistry of these layers aloft needs further attention before it can be incorporated properly into modeling activities. Air quality data useful for validating the nighttime chemistry components of models would be particularly useful (hydrocarbons, NO_x, PAN, etc.).

5. Knowledge of hydrocarbon concentrations and speciation in the layers aloft and in the pollutants transported offshore is currently minimal. Hydrocarbon measurements at these locations as well as at surface onshore locations will be needed as input to the chemical modules of any model used and may also be useful for distinguishing air samples originating in Ventura County from those originating in the South Coast Air Basin. Measurements of oxygenated hydrocarbons (e.g. formaldehyde) would be especially useful to the modeling community.

2.3 RECOMMENDATIONS

Further quantification of the relative contributions of various sources to Ventura County ozone concentrations will likely require a sophisticated modeling effort and substantial additional measurements. The modeling could be performed with a three-dimensional grid model or with multi-layer trajectory models; but in either case, a large amount of data on initial, boundary, and transport conditions will be needed. The wind fields in the region are strongly influenced by terrain, and land-sea interactions and are very complex. They vary greatly from day-to-day, and the frequency of occurrence of various regimes varies from month to month. The pollutant fields have strong horizontal and vertical gradients as well. To obtain the data needed for modeling, it is likely that an intensive three-dimensional data collection effort covering several meteorological regimes will be needed. Since the ozone distribution is a result of multi-day processes, it is clear that three-dimensional data will be required for at least 24-hour periods.

Quantification of the impact of high ozone concentrations in elevated layers on elevated terrain will require the same type of modeling as for the valley sites. In addition, however, to determine the frequency and magnitude of the impact on elevated terrain, some long term monitoring at elevated locations is recommended.

Many of the above requirements will be met by the upcoming South Central Coast Cooperative Aerometric Monitoring Program (Dabberdt, et al. 1985). Some specific measurement recommendations are outlined below.

1. The importance of the wind along the coast at about 1000 m msl has been stressed. A continuous record from a Doppler Acoustic Sounder located on the Oxnard plain would permit a better assessment of the transport wind characteristics.

2. The Laguna Peak location is an excellent place and height to monitor the ozone transport from the South Coast Air Basin into Ventura County. It is also a good location to measure the effects of elevated pollutant layers. Efforts should be made to maintain an ozone monitor at that location to permit a better evaluation of transport throughout the year. Long term data at this site along with the upper wind data mentioned above would be helpful to analysts in quantifying the importance of the transport processes aloft.

3. Additional elevated sites which would be useful additions to the routine monitoring network in Ventura County are the Rocketdyne (or similar) site (which has been operated until recently by Rockwell International) and a site at South Mountain. Data from these sites along with Laguna Peak, could provide a good indication of the frequency and magnitude of elevated layers.

4. The fate and eventual impact on surface concentrations of the elevated layers in the coastal regions could be assessed by tracer releases into the layers. Releases could be conducted in the morning to assess same day impacts and in the evening to assess next day effects.

3. CONCEPTUAL MODEL AND CASE STUDIES OF TRANSPORT FROM THE SOUTH COAST TO THE SOUTH CENTRAL COAST AIR BASIN

3.1 BACKGROUND

An early recognition of the presence of ozone aloft over Ventura County was provided by Lea (1968). High ozone concentrations were frequently found within the temperature inversion at Pt. Mugu at a level of 500-600 m agl. A wind rose was constructed for the altitudes of the high ozone layers coincident with these occurrences. The wind rose indicated that concurrent winds were primarily from northeast to south-southwest and it was concluded that the Los Angeles area was a likely source of the high ozone aloft.

Kauper and Niemann (1975) conducted a brief study of ozone and wind profiles between Santa Monica and Ventura for CARB. Layers of high ozone concentrations were observed aloft within the temperature inversion at both locations. The study period included a three-day ozone episode in Southern California (July 9-11, 1975). The peak ozone concentration observed at Oxnard was listed as 0.43 ppm at 1400 PST on July 10th. This concentration occurred at 900 ft. msl above an inversion base at 700 ft. msl. A trajectory analysis placed this air parcel in the Santa Monica area shortly after midnight on July 9-10. The estimated trajectory was westward and thence north and northeastward, arriving at Oxnard with the afternoon sea breeze flow. Estimated trajectories for high ozone concentrations observed aloft at 1100 PST at Oxnard on nine occasions indicated transport from the San Fernando Valley (3 cases) and along an offshore route from Los Angeles (6 cases). It was suggested that the over-water transport route was more likely when the inversion base was relatively low.

Strange and Hovind (1976) observed an ozone layer (or layers) aloft in an aircraft flight between Santa Barbara and Ventura. The peak ozone reported was 25 pphm at 1400 ft. msl within the temperature inversion offshore from Ventura. The time of the flight was about 1500 PST on August 25, 1976.

Shair et al. (1982) conducted an SF_6 tracer study by releasing material from the stack of a power plant in El Segundo between 2300 and 0400 PST on July 22, 1977. The tracer material was carried offshore by the land breeze and subsequently returned to the coast by the afternoon sea breeze. Significant concentrations of SF_6 were observed along the coast between Ventura and Pt. Mugu beginning at 1100-1200 PST and continuing through 1600 PST. The bulk of the material, however, returned to the coast within the South Coast Air Basin.

An extensive tracer and observational study was carried out in the Santa Barbara/Ventura area by CARB in September 1980 (Smith et al., 1983). Results of the study are of interest from a transport standpoint in the following ways:

1. Tracer releases (October 1 and 3, 1980) were made between Port Hueneme and Platform Grace during the morning (0500-1000 PST and 2345-0445 PST, respectively). Tracer trajectories indicated transport as far west as Santa Barbara before the sea breeze wind flow reversal.

These trajectories indicate that significant transport into Santa Barbara from the southeast can occur over distances of 100 km or more.

2. Afternoon aircraft soundings (September 28 and October 3, 1980) near the Simi Hills showed strong ozone layers aloft (23 and 13 pphm, respectively) at elevations of about 1000-1200 m msl. These layers were observed to be associated with east or southeast winds and appear to have been transported from the San Fernando Valley to the eastern edge of the South Central Coast Air Basin.

3. On October 2, 1980, anomalous ozone peaks were observed at Ventura and Port Hueneme between 1900 and 0000 PST, well after the diurnal ozone maximum had occurred. Ozone readings at Platform Grace indicated a peak value of 13 pphm at 1200 PST with a southeast wind. Subsequently, the wind shifted to a westerly, sea breeze direction. Backward trajectories indicated that the high ozone concentrations at Platform Grace and, during the evening along the coast, probably originated in the South Coast Air Basin and were then transported northwest offshore into the South Central Coast Air Basin.

Finally, Godden and Lague (1983) provide detailed summaries of the available literature regarding possible pollutant transport between the South Coast and South Central Coast Air Basin.

The information summarized above provides strong indications of pollutant transport from the South Coast to the South Central Coast Air Basin under appropriate meteorological conditions. Two transport routes have been suggested:

1. Offshore from the Santa Monica/LAX area and thence northwestward to the Ventura/Pt. Mugu area where the material may be brought onshore by the sea breeze.

2. Transport from the San Fernando Valley westward into the South Central Coast Air Basin where concentrations aloft might be fumigated to the surface.

3.2 CONCEPTUAL MODEL OF TRANSPORT

The foregoing studies and the results of the September 1983 field program lead to the following scenarios for transport from the South Coast Air Basin to the South Central Coast Basin.

3.2.1. Offshore Transport

During the night and early morning hours of summer, low-level winds along the Southern California Coast frequently have an easterly component. Table 3-1 gives the frequency of occurrence of offshore winds at Loyola-Marymount (near LAX) and at Pt. Mugu for several months of the summer during the years of 1980-83.

Table 3-1. Frequency of Occurrence of Early Morning Offshore Winds (0500 PST)

Month	Height (ft. agl)	Frequencies: Loyola-Marymount (%)	Frequencies: Pt. Mugu (%)
July	1000	66	69
	2000	68	68
	3000	46	48
August	1000	63	66
	2000	56	77
	3000	45	77
September	1000	59	54
	2000	67	63
	3000	62	64

As indicated in Table 3-1, the coastal winds at night frequently have the potential for transport of pollutants into the offshore areas. The extent of this transport and the height at which it occurs are highly dependent on the overall synoptic weather conditions. Above normal pressure gradients from the coast to the inland areas decrease the effectiveness of the offshore transport while weak onshore or offshore pressure gradients increase the opportunity for such transport. It is often apparent that a shallow onshore flow layer may exist during the night near the surface underneath an offshore flow at 2000-3000 ft. Consequently, the surface winds along the coast are not always reliable indicators of the existence of offshore flow. The nocturnal pollutant transport may occur in the shallow layer near the surface or in an elevated layer separated from the surface.

Heating of the inland areas during the day typically initiates a sea breeze flow along the coast. Table 3-2 gives the median initiation times for the sea breeze at Pt. Mugu and LAX.

Table 3-2. Median Development of the Sea Breeze Flow at Pt. Mugu and LAX (obtained from surface data for 1979 and 1980)

	Pt. Mugu Beginning (PST)	Pt. Mugu End (PST)	LAX Beginning (PST)	LAX End (PST)
July	0900	1900	0900	2200
August	0900	1900	0900	2300
September	0900	1800	0900	2100

The sea breeze flow has characteristically stronger velocities than the nocturnal flow but, in the case of Pt. Mugu, is present for a shorter portion of the 24 hour day.

The sea breeze flow provides a mechanism for the return of pollutants which have been transported offshore during the previous night. As suggested by the above data, this process may occur in the Ventura area as well as the South Coast Air Basin.

The trajectory of pollutant material carried offshore from the South Coast Air Basin is determined largely by the overall meteorological situation. This was well illustrated by Shair et al. (1982) who released tracers on successive nights from the South Coast Basin. Tracers released one night returned to the coast at Ventura and Santa Monica, while the tracer released the next night returned to the region between Santa Monica and Long Beach.

Schematic trajectories indicating the transport routes between the South Coast and the South Central Coast Air Basins are shown in Figure 3-1. As expected in any transport situation, the impact of the transport is influenced strongly by the dispersion which occurs along the transport route. Offshore transport from the South Coast Air Basin to the South Central Coast Basin may occur but may have insignificant impact due to extensive mixing along the route.

3.2.2 Transport from the San Fernando Valley

Another potential transport route from the South Coast Air Basin to the South Central Coast Basin is from the San Fernando Valley over the Simi Hills into the eastern portions of Ventura County. Since the San Fernando Valley experiences high ozone concentrations during the summer months, there is reason to expect that easterly winds could transport these pollutants into the South Central Coast Air Basin.

The diurnal distribution of winds across the Simi Hills is similar to that observed along the coast. The frequency of easterly winds increases at night and in the early morning but decreases markedly during the afternoon when the sea breeze dominates the flow. The median beginning and ending times of the westerly flow at Rocketdyne (1800 ft. msl in the Simi Hills) are shown in Table 3-3.

Table 3-3. Median Development of Westerly Flow at Rocketdyne (1981-83)

	Begin	End
July	1100 PST	2100 PST
August	1100	2100
September	1200	2000

A series of pibal wind soundings at Simi at 0400 PST during September 1980 showed a frequency of about 70% for north-northeast to southeast winds at 1000 m msl which is a reasonable transport level across the Simi Hills.

From Table 3-3, there is a potential for easterly surface transport into the South Central Coast Air Basin until a median time of 1100 to 1200 PST. Although there is a realistic potential for transport into the Basin, the impact of this transport needs to be considered.

Table 3-4 shows the median top of the mixing layer at Camarillo and Simi in September 1983 for several times of day. These heights were obtained from the VCOT aircraft soundings.

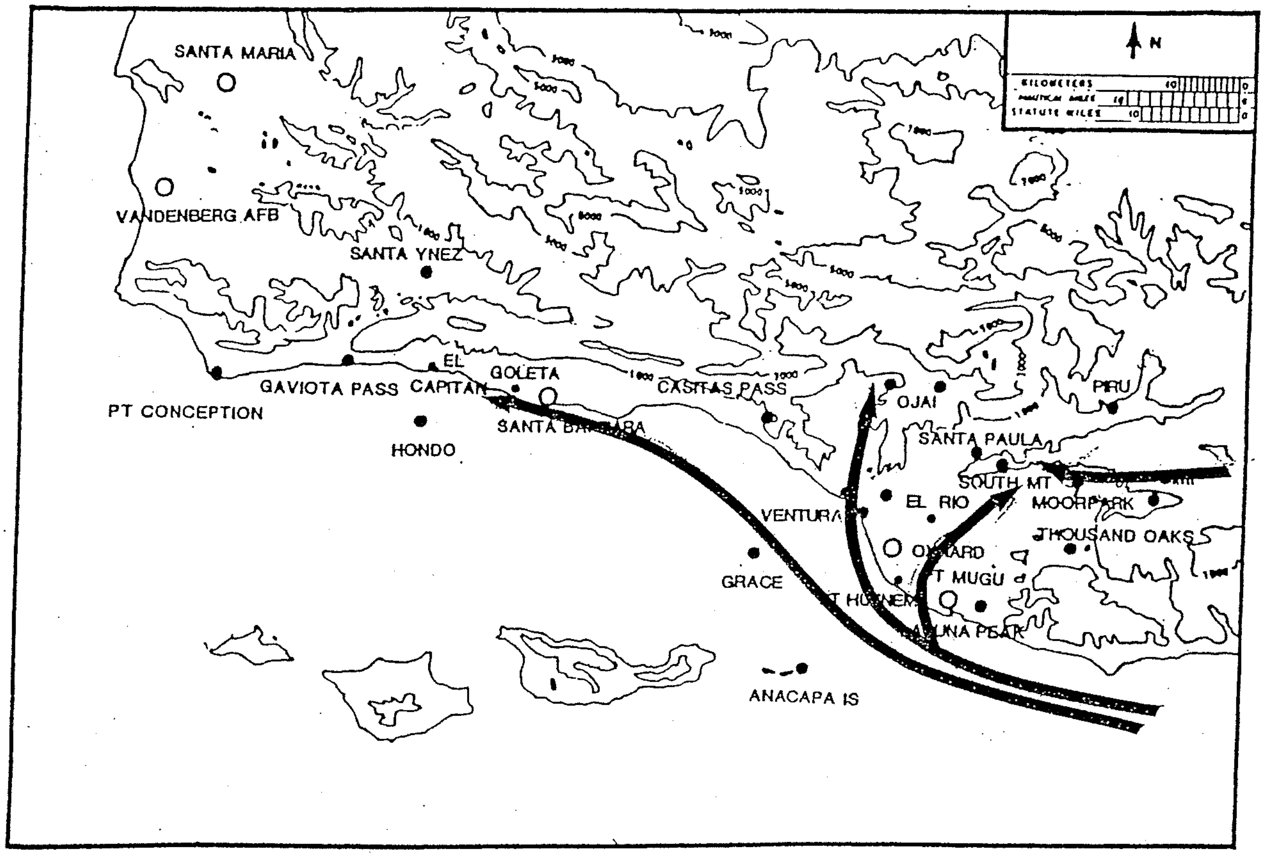

Figure 3-1. Schematic View of Transport Routes from the South Coast Air Basin to the South Central Coast Air Basin.

Table 3-4. Median Top of Mixed Layer During the VCOT Aircraft Soundings (September 1983)

Camarillo		Simi	
Approximate Time (PST)	Top of Mixing (m msl)	Approximate Time (PST)	Top of Mixing (m msl)
0600	100	0700	400
0900-1000	300	1000	750
1400-1500	300	1600	750

The data in Table 3-4 indicate that the mixing depth in the Simi area frequently reaches a height above the Rocketdyne station (elev. 550 m msl), and hence any pollutant material moving westward past Rocketdyne could be readily incorporated in the mixed layer and brought down to the level of Simi (elev. 335 m msl). The timing of the mixed layer growth to the level of the Rocketdyne station is generally indicated by the shift to a northwesterly wind at Rocketdyne. From Table 3-3, this occurs with a median time of 1100-1200 PST.

Table 3-4, however, indicates a much lower mixing layer top at Camarillo which can be considered as representative of the coastal plain. The data in the table suggest that the mixing depth at Camarillo does not usually reach the altitude of the Rocketdyne station. Pollutant material carried westward over the plain would therefore be unlikely to be mixed down directly to the surface layers near the coast.

The fate of this elevated pollutant layer moving westward is somewhat uncertain. Mixing downward over the coastal plain is severely inhibited by the temperature inversion which exists above the sea breeze flow. Whether the elevated layer can be carried out over the ocean and incorporated in the next day's sea breeze is not known. The layer could, however, impact on higher terrain to the south and northwest of the Ventura coastal plain, e.g. Laguna Peak and Ojai. In addition, ventilation to the surface at Piru would probably occur in a similar way as at Simi.

Lidar data (McElroy, 1983) have confirmed that the region of potential interchange between surface layers and the elevated layer is confined to a distance of 15-20 km westward from the crest of the Simi Hills. Beyond this distance, the depth of the mixed layer is not sufficient to bring about the interchange. This limits the direct impact of transport from the San Fernando Valley to a narrow distance along the western slopes of the Simi Hills and to the upper reaches of the Santa Clara River valley where rising terrain and slope heating combine to bring about rapid increases in mixing depth.

3.3 CASE STUDIES

The inland and coastal (over-water) transport routes described above have been further sub-divided into surface and elevated categories, representing the relative altitude of transport. Three case study days from the September 1983 VCOT sampling period are described below which illustrate these various routes. More than one route can occur on a given day.

3.3.1 September 11, 1983

3.3.1.1 General Meteorology

High pressure was present in the Pacific Northwest (Figure 3-2), following the passage of a low pressure system through the area on the 10th. The surface thermal low pressure area extended as far north as northern California but was located along the coast, to the west of its normal summer position. The pressure gradient aloft (500 mb) was very flat with light, easterly winds at most locations in California and southern Nevada. High scattered clouds were reported during the day in the South Central Coast Air Basin. Lowest visibilities reported during the day were 8 miles at Pt. Mugu. No low clouds were observed on the 11th below 5000 ft msl.

Significant meteorological parameters for September 11, 1983 are summarized in Table 3-5.

Table 3-5. Meteorological Parameters for September 11, 1983

	9/11/83	Long Term Average*
850 mb Temperature at 0400 PST (Vandenberg AFB)	24.5°C	18.1°C
Surface Pressure Gradients (0400 PST)		
San Francisco - Reno	-5.1 mb	-1.2 mb
Los Angeles - Bakersfield	-3.2	-0.1
Los Angeles - Las Vegas	-2.4	1.6
Inversion Bases		
Loyola-Marymount (0600 PST)	surface	
Loyola-Marymount (1100 PST)	250 m agl	
Upper Winds (1000 m msl)		
Loyola-Marymount (0600 PST)	030°/1 m/s	
Loyola-Marymount (1100 PST)	330°/1.5 m/s	
(Pt. Mugu Sounding data not available)		

*average September values (1980-83)

Meteorological conditions on September 11, 1983 reflected the early phases of an extended period of warm temperatures aloft and relatively high ozone concentrations. This sequence began on September 10th and lasted through September 19th. By September 11th, the temperature at 850 mb was well above average, and the surface pressure gradients were strongly directed offshore from central California to southern California. These conditions represent the initial stages of a characteristic cycle which begins with offshore

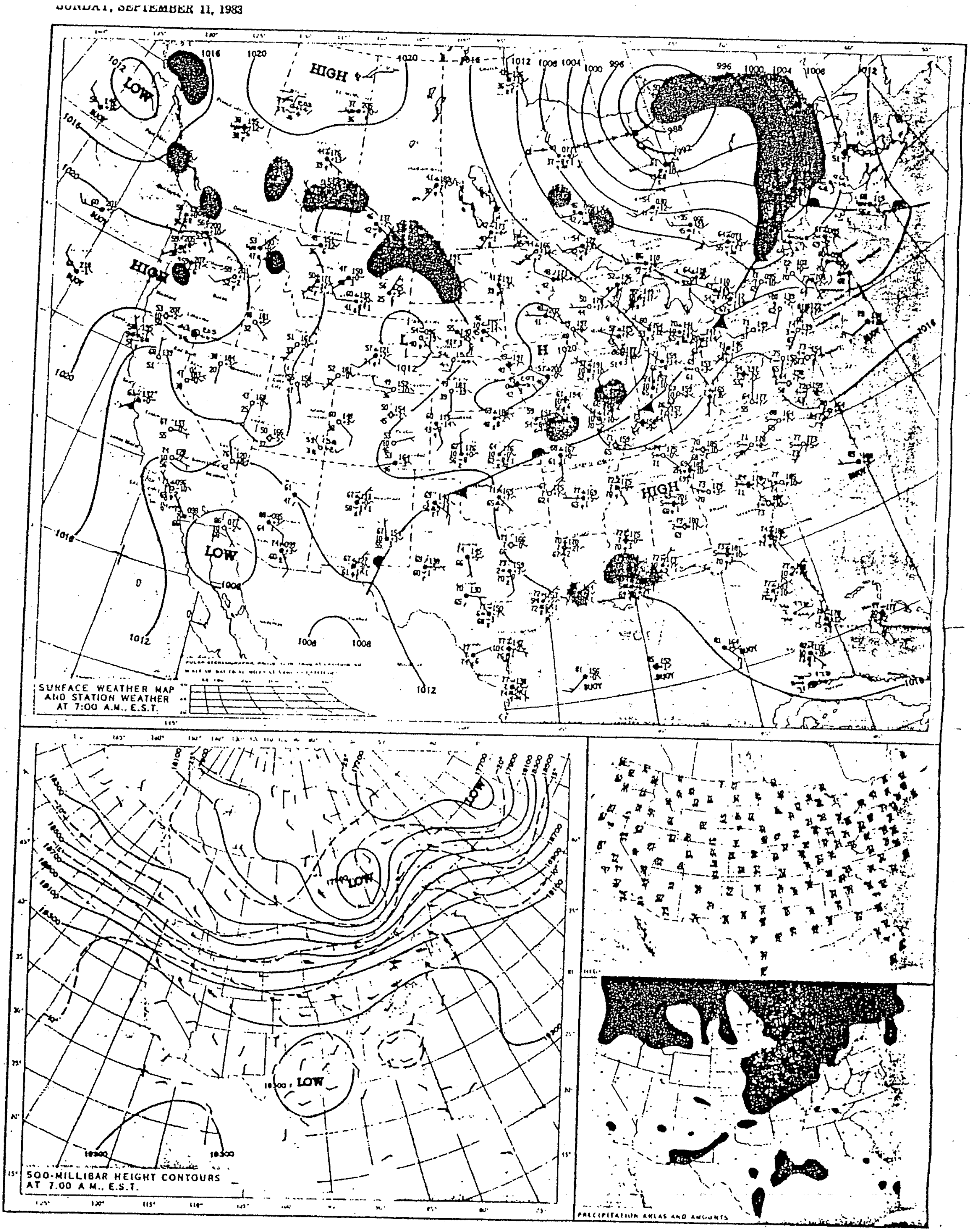

Figure 3-2. Surface and 500 mb Synoptic Weather Maps for 11 September 1983 at 0400 PST.

transport of pollutants, passing through a stage of stagnant conditions (weak pressure gradients) and ending with the return of onshore gradients and a stronger westerly flow.

3.3.1.2 Transport Winds

Table 3-6 gives the surface wind observations for several locations of interest on September 11th.

Table 3-6. Surface Transport Wind Summary for September 11, 1983

Time (PST)	Laguna Peak (degrees/ m/s)	Platform Grace (degrees/ m/s)	Pt. Mugu (degrees/ m/s)	Santa Barbara (degrees / m/s)
0600	calm	356/0.9	030/1	calm
0800	calm	320/1.7	calm	calm
1000	calm	262/3.3	250/1	250/3
1200	230/2	259/3.6	260/2	240/4
1400	260/3	230/5.9	260/3	240/6
1600	320/6	277/4.8	300/2	240/6
1800	330/7	243/7.1	300/2	210/3
2000	310/8	256/4.5	320/1	130/2
2200	290/6	224/3.3	290/3	calm

A summary of wind directions at 1000 m msl obtained by the doppler acoustic sounder at Simi is given in Table 3-7. Recorded wind speeds at that level were higher than could be substantiated by other data and are not presented.

Table 3-7. Doppler Acoustic Sounder Wind Directions at Simi at 1000 m msl for September 11, 1983

Time (PST)	Wind Direction (degrees)	Time (PST)	Wind Direction (degrees)
0800	025	1600	145
1000	135	1800	162
1200	141	2000	142
1400	146	2200	267

The surface wind flow patterns on September 11th indicated southwest to northwest winds during the midday and afternoon hours throughout the area. There was no indication of southerly flow in the offshore area which could have transported pollutants from the South Coast Air Basin at surface levels.

The 1000 m msl winds at Simi were consistently from the southeast until late in the evening. West-southwest winds existed at Simi to levels of 600 m msl by 1200 PST, increasing to a 1000 m msl top by 2200 PST.

3.3.1.3 Mixing Heights

The primary sources of mixing height data are aircraft soundings where an evaluation of the pollutant and temperature profiles usually provides a good indication of the effective mixing depth. A summary of the aircraft sounding data for September 11th is shown in Table 3-8.

Table 3-8. Mixing Heights from Aircraft Soundings for September 11, 1983

	Time (PST)	Mixing Depth (m agl)
Camarillo (sfc. elev. 25 m)		
	0519	50
	0920	75
	1412	275
Pt. 2 (3 mi SSW Laguna Peak, over water)		
	0532	100
	0932	100
	1426	125
Pt. 3 (13 mi. SSW Laguna Peak, over water)		
	0554	225
	0948	200
	1443	150
Westlake Reservoir(sfc.elev. 305 m)		
	0622	100
	1015	200
	1510	300
Simi (sfc.elev. 335m)		
	0639	-
	1033	165
	1527	295

As indicated in Table 3-8, all mixing heights were relatively low, in keeping with the warm temperatures aloft. Mixing heights over the land areas increased substantially during the day but remained relatively low compared to average conditions.

3.3.1.4 Regional Ozone Concentrations

Maximum ozone concentrations observed in the South Central Coast Air Basin on September 11th are given in Table 3-9 together with the times of observance of the maximum values and the winds observed at the monitoring stations at the times of the maxima.

Table 3-9. Maximum Hourly Ozone Concentrations on September 11, 1983

Location	Maximum Concentration (pphm)	Time of Maximum (PST)	Wind (deg/(m/s)
Ojai	M*	M	
Piru	11	13	264/M
Simi	10	15-17	285/3
Thousand Oaks	12	13	
Rocketdyne	11	14	329/5
El Rio	14	15-16	
Laguna Peak	11	15	270/6
Ventura	10	16	270/5
La Conchita	10	15	
Santa Barbara	12	13	270/4
Goleta	13	13	
El Capitan Beach	9	14-15	

* M = missing data

Observed exceedances of the 12 pphm ozone standard occurred at El Rio and Goleta. In contrast to the normal occurrence, high ozone values were observed near the coast rather than in the inland areas. As will be indicated later, this situation frequently occurs under conditions of very low mixing height.

3.3.1.5 Transport Analysis

Figure 3-3 shows the hourly ozone concentrations for a number of stations in Ventura County on September 11th. The diurnal patterns are characterized by relatively late ozone peaks. Average ozone maxima in Ventura County occur about 1300-1400 PST (Smith et al., 1983). Although there are indications of an earlier peak in the Figure 3-3 data (e.g. Piru) there is evidence of a somewhat stronger peak at 1600-1700 PST (1500 PST at Laguna Peak). It is also to be noted that the peaks at Simi and Piru are extended through 1700 PST. The data tend to suggest a peak which arrived first at Laguna Peak and subsequently at Ventura/El Rio and then at Piru/Simi. In contrast, Santa Barbara and Goleta had single ozone peaks, centered at 1300 PST.

Figures 3-4 through 3-7 show early morning aircraft soundings for September 11th at Camarillo, at two offshore locations, and at Westlake Reservoir. All of these soundings show significant temperature inversions in the low layers but are without any indications of high ozone concentrations aloft. The peak ozone concentration reported on any of the soundings was about 8 pphm. Available wind observations at Loyola-Marymount showed southeasterly winds in the lowest 300 m at 0600 PST. Doppler acoustic sounder winds at Simi indicated a shallow southeasterly flow in the lowest 150 m agl. There were no sounding observations taken at Pt. Mugu on September 11th.

Figures 3-8 and 3-9 show the aircraft soundings made at Camarillo and offshore at 3 mi SSW of Laguna Peak in the late morning. A shallow mixing layer had developed at Camarillo due to surface heating. A peak ozone concentration of 11 pphm occurred near the base of the temperature inversion. Offshore, the surface temperature inversion remained, and a peak ozone value of 17 pphm existed at a level of 150-200 m msl within the temperature inversion.

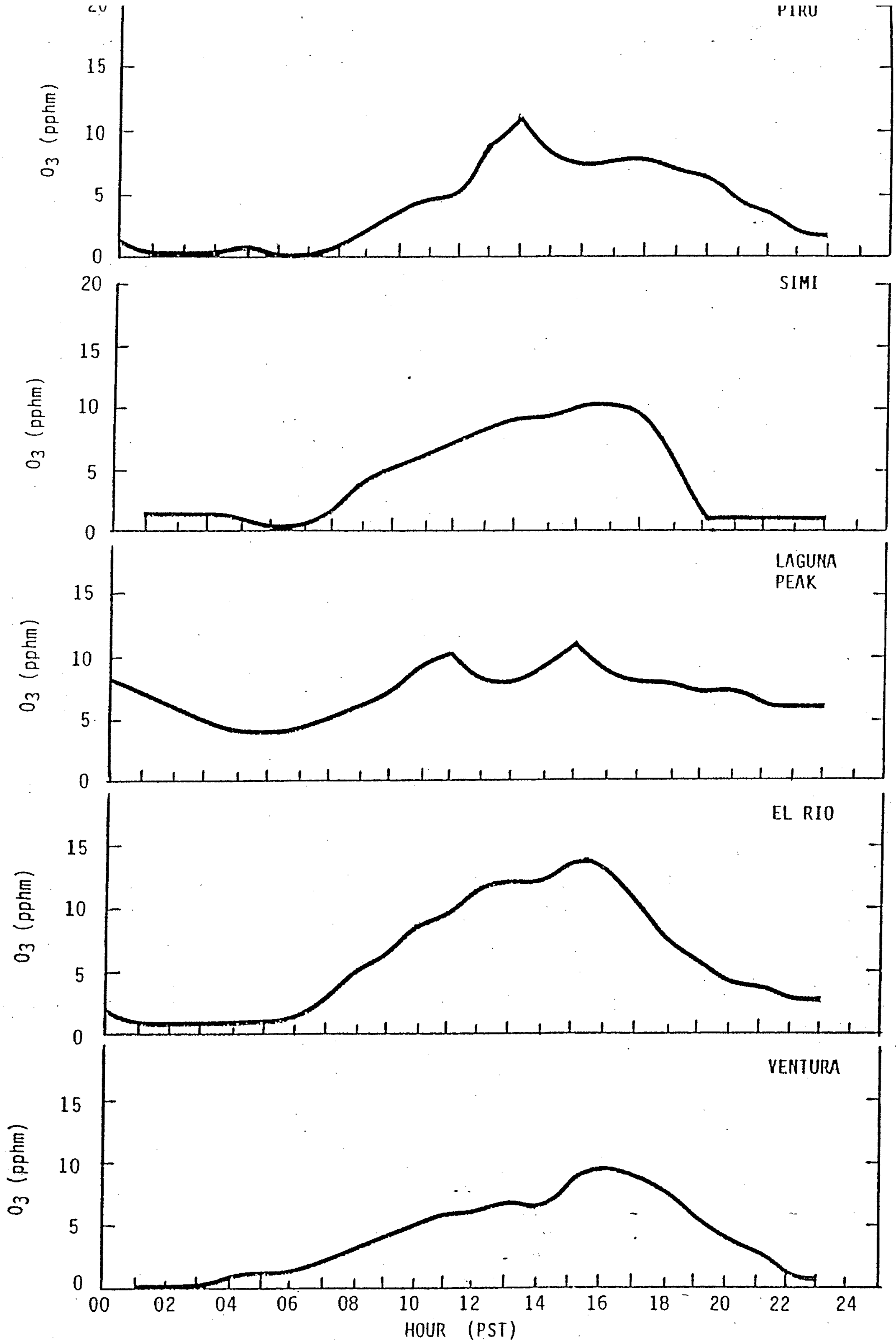

Figure 3-3. Hourly Average Ozone Concentrations for 11 September 1983.

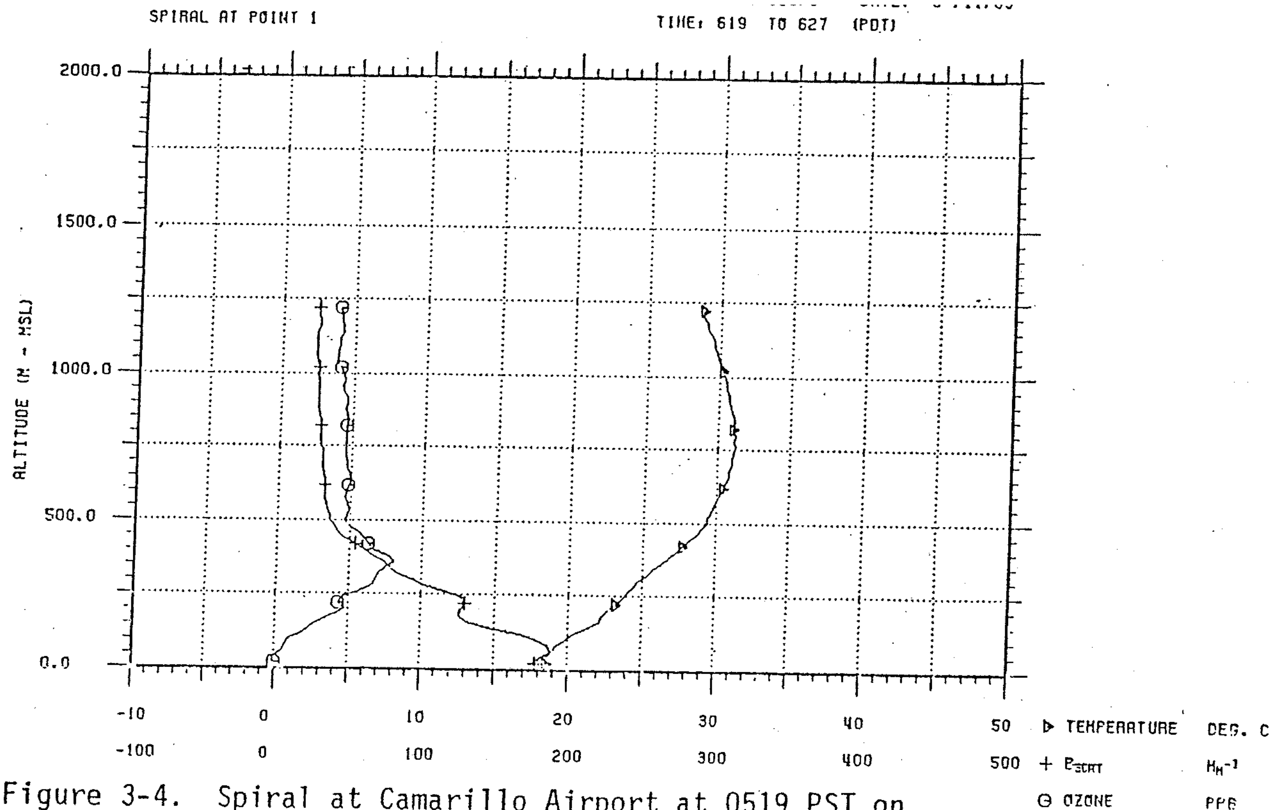

Figure 3-4. Spiral at Camarillo Airport at 0519 PST on September 11, 1983.

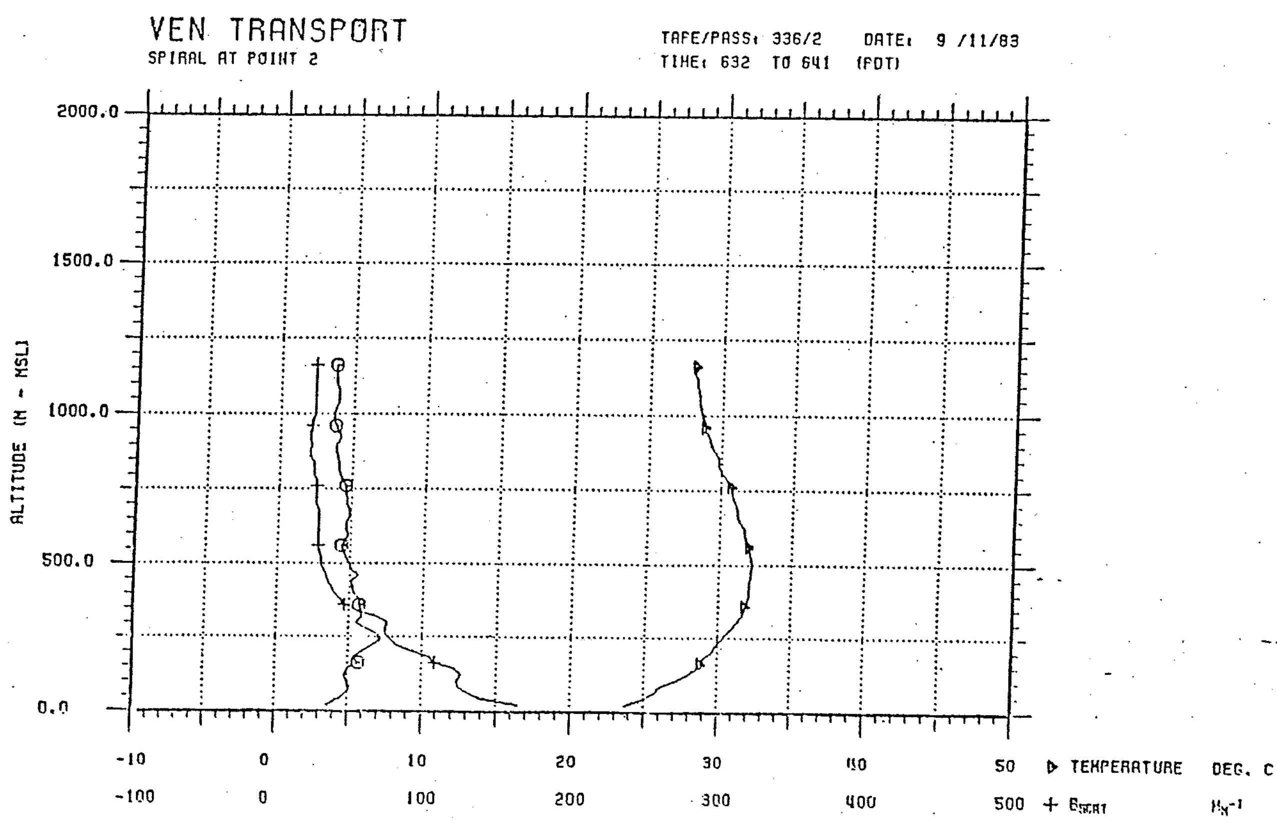

Figure 3-5. Spiral Offshore of Laguna Peak at 0532 PST on September 11, 1983.

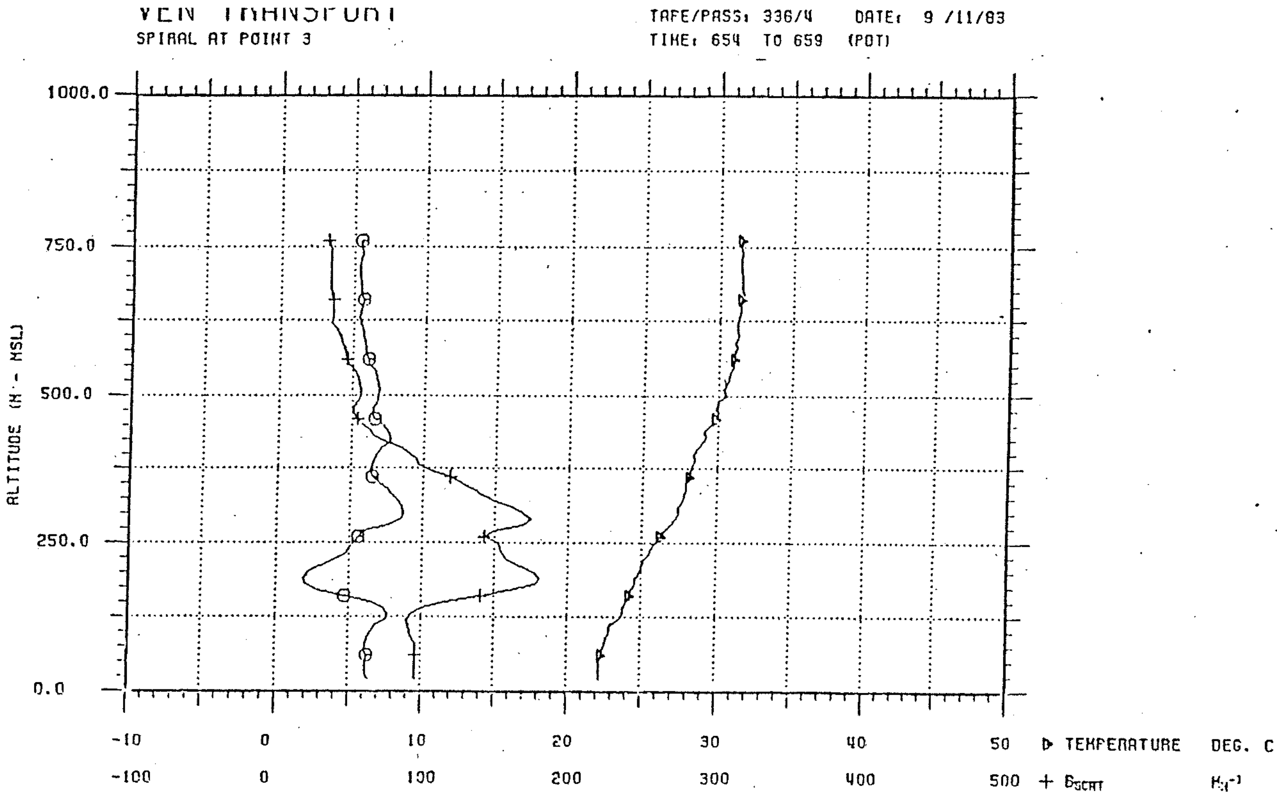

Figure 3-6. Spiral about 10 Miles South of Pt. Mugu at 0554 PST on September 11, 1983.

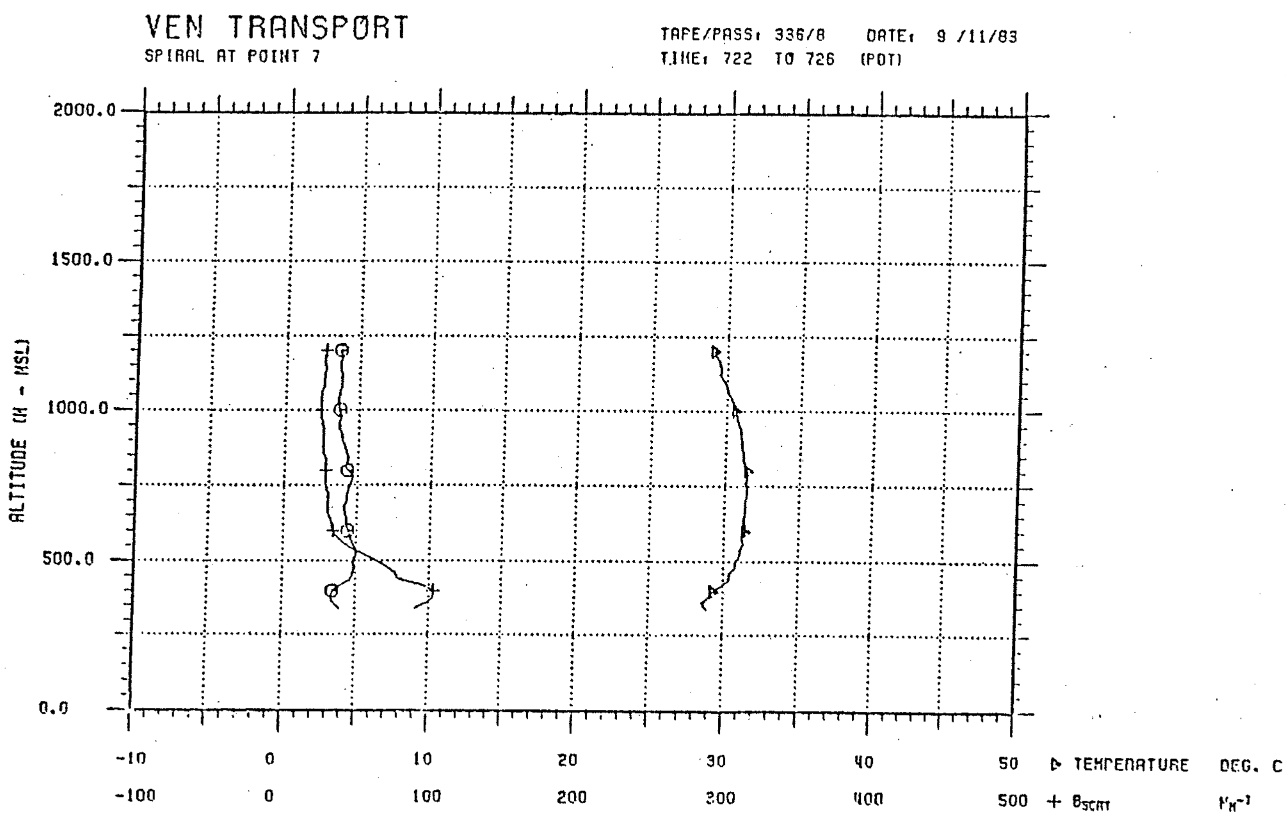

Figure 3-7. Spiral at Westlake Reservoir at 0622 PST on September 11, 1983.

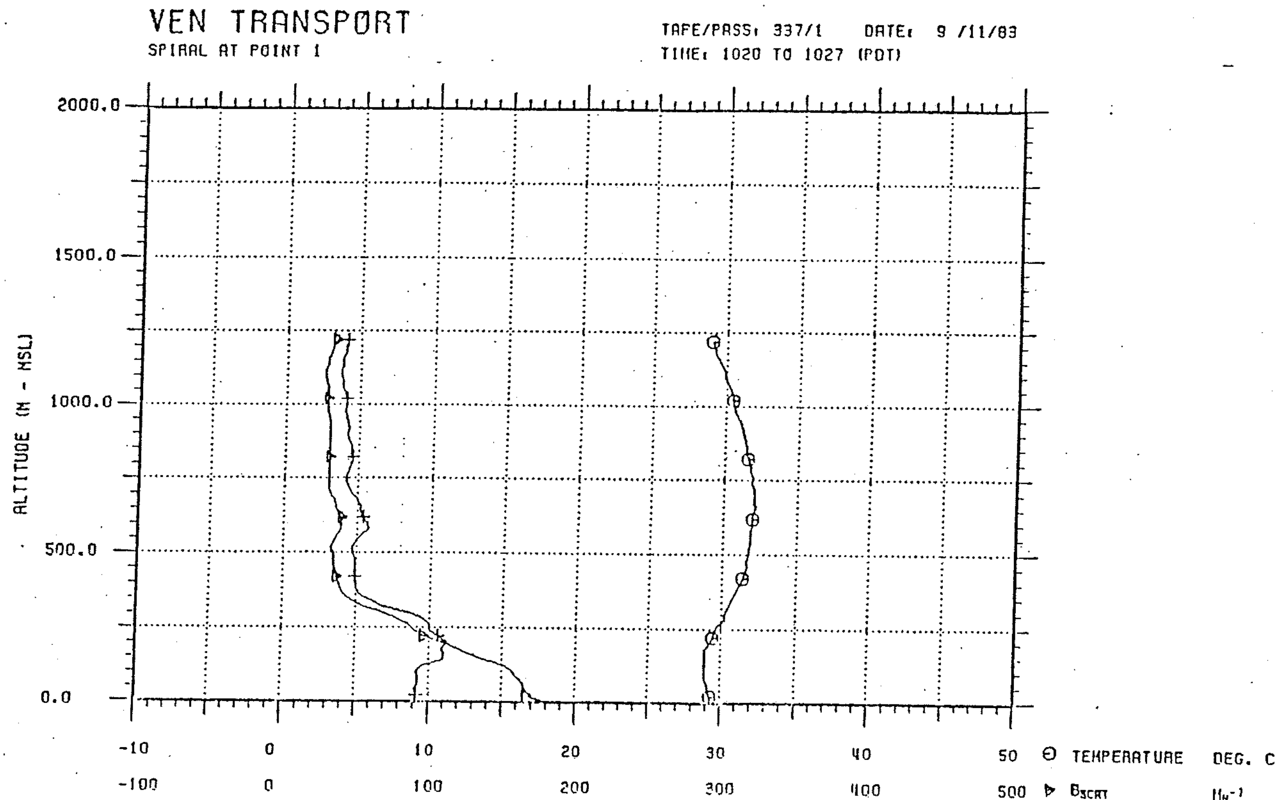

Figure 3-8. Spiral at Camarillo Airport at 0920 PST on September 11, 1983.

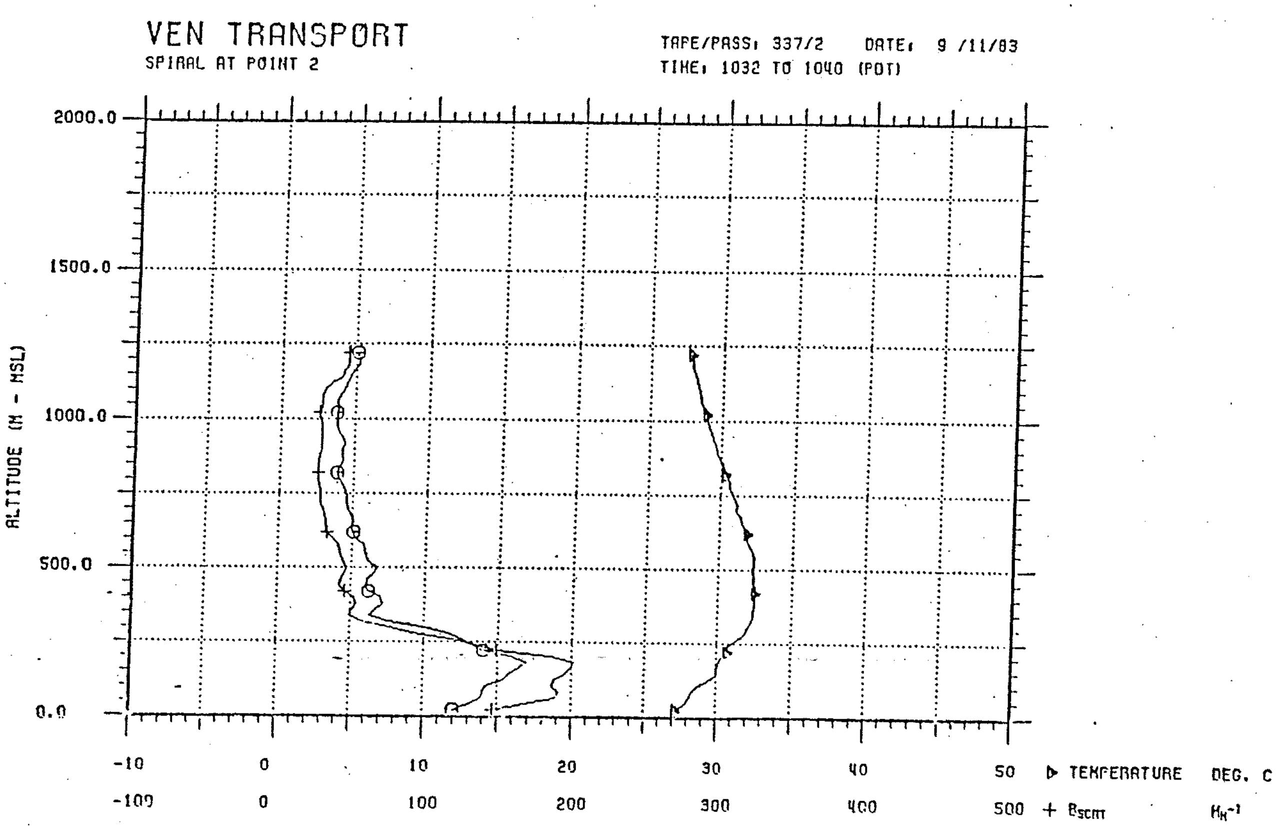

Figure 3-9. Spiral Offshore of Laguna Peak at 0932 PST on September 11, 1983.